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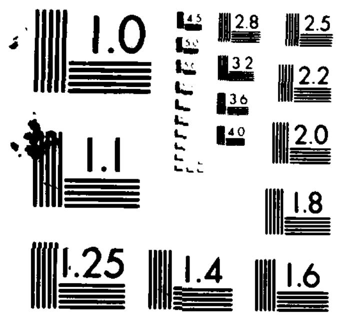

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Temporal Structure and Interpretability in The Classification of Nonspeech Acoustic Patterns

James H. Howard, Jr. and James A. Ballas

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Department of Psychology

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Two experiments investigated the role of syntactic (sequential structure) and semantic factors in the classification of complex environmental sound patterns. The results of the first experiment were consistent with our earlier findings in revealing that 1) sequentially structured, interpretable patterns are classified more accurately than unstructured patterns, 2) an explicitly provided semantic context enhances initial classification performance with interpretable patterns,

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however, 3) no semantically-related enhancement results with unstructured, uninterpretable patterns. Experiment 2 examined classification of sequentially-structured, but minimally-interpretable patterns. The results showed that 1) sequential structure alone can lead to optimal classification performance, and 2) providing explicit semantic information impaired performance with these patterns. In both experiments listeners appeared to learn something about the composition rules used to produce the target patterns rather than simple paired-associate responses. Syntactic and semantic factors play a role in the classification of complex nonspeech patterns.

Many recent studies have investigated the role of syntactic and semantic factors in listeners' comprehension of continuous speech. The evidence is compelling and unambiguous in revealing the importance of top-down processes in this situation (Cole, 1980). Despite this, only recently have investigators examined the possibility that similar top-down processing occurs in the perception of some complex nonspeech sound patterns. Everyday experience suggests that expectancies are involved in our ability to decipher the variety of nonspeech stimuli we encounter. More specialized listening skills can also be seen in some individuals. For example, a sonar technician must identify the source and activity represented by the sounds recorded on passive sonar hydrophones. Such sounds often occur in sequences or patterns in which the temporal structure (sound order) can provide important cues about what the source vessel may be doing (Howard & Ballas, 1980). Similarly, the technician's extensive knowledge of the sources producing these sounds appears to influence his or her perceptual capability. The present study reports two experiments which investigate the role of syntactic and semantic factors in the classification of complex, nonspeech patterns.

Several investigators have presented evidence that top-down processing does occur for nonspeech stimuli (Deutsch, 1980; Howard & Ballas, 1980; Bregman, 1981). For example, Bregman (1981) has demonstrated that listeners employ Gestalt rules or principles to segment acoustic information from different sources. He has referred to this phenomenon as auditory streaming.

Research in our laboratory has suggested that listeners are able to use both syntactic and semantic information in a relatively simple auditory pattern classification task (Ballas & Howard, 1980; Howard & Ballas, 1980). Four groups of listeners were required to classify patterns of brief duration real-world sounds as "targets" or "nontargets." For the grammatical group target patterns were produced using a simple finite-state rule structure or grammar to determine the sequential order of the pattern components. In contrast, target patterns for the nongrammatical group matched the grammatical patterns in length, but were randomly constructed. As a result, the target set for the latter, nongrammatical group lacked the overall coherence or structure present in the grammatical target set.

In addition, each of the five pattern components was related to water or steam (e.g., the squeak of a valve turning, steam hiss, water flushing down a drain, etc.), and the finite-state grammar was selected to produce only interpretable patterns. In other words, the grammar reflected the temporal structure of possible real world events. For example, one pattern might represent someone taking three turns to open a valve that releases steam, which, in turn, causes pipes to clang. Each of the grammatical patterns could be described by a similar source scenario corresponding to events that might actually occur. Although similar interpretations obviously can be applied to some randomly constructed patterns, overall the nongrammatical target patterns were only minimally interpretable. To evaluate the role of semantic information in nonspeech pattern classification, one-half of the participants in each of the two groups were read a brief paragraph which suggested a theme for the patterns they would hear. The paragraph was general and did not identify any specific patterns. The remaining individuals received no explicit semantic information about the patterns.

Three findings were reported (Howard & Ballas, 1980). First, listeners who classified the grammatical target patterns performed substantially better than those who classified the unstructured or random target patterns. Second, listeners in the grammatical group who received semantic information performed at a higher level than those who did not receive this information. Third, the semantic information did not enhance performance for listeners in the nongrammatical group. On the contrary, there was some evidence that the semantic information actually impaired performance for these listeners. Overall, it was concluded that syntactic and semantic factors interact to influence nonspeech pattern classification. The two experiments reported in the present paper replicate (Experiment 1) and extend (Experiment 2) these findings.

Experiment 1

In this experiment participants were required to classify patterns of complex, water- and steam-related sounds. As in our previous research some individuals received structured or grammatical target patterns whereas others received an unstructured or randomly generated target set. One-half of the individuals in each condition were read a general descriptive passage which suggested a water/steam semantic context for the patterns they were to hear. The remaining participants were given no explicit semantic information. Overall, the experiment is a replication of our earlier study; however, a six-point rating scale procedure was employed to obtain a full receiver operating characteristic (ROC) for each listener.

Method

Participants. Twenty student volunteers, five in each of four groups, were paid to participate in the experiment.

Stimuli. Five brief-duration, "real-world" sounds were recorded in our laboratory (a radiator valve being turned, water drip, broadband steam hiss, the clang of a metal object striking a radiator pipe, and water flushing down a drain). The sounds were digitized using standard signal processing techniques with a 10-bit analog-to-digital converter at a 12.5 kHz sampling rate. Each sound was 320 ms in duration with the exception of the water drip which was 82 ms long.

The grammatical target patterns were produced using the simple finite-state grammar described in Howard & Ballas (1980, p. 432). Twelve grammatical patterns ranging in length from four to six events (three, four, and five patterns of each length, respectively) were selected to make up the grammatical target category. A corresponding nongrammatical target set was produced by randomly permuting the order of pattern components in the grammatical target set. Consequently, the nongrammatical targets matched the grammatical targets in length and composition. Similarly, 48 randomly constructed nontarget patterns were selected to be nonoverlapping with the target sets but to match them in length. Each component was presented at a comfortable listening level and the individual components were separated by 510 ms within the patterns.

Apparatus. All experimental events were controlled by a general-purpose laboratory computer. The acoustic patterns were output on a 12-bit digital-to analog converter at a sampling rate of 12.5 kHz, low-pass filtered at 5 kHz (Khron-Hite Model 3550), attenuated, and presented binaurally over matched Telephonics TDH-49 headphones with MX-41/AR cushions. Testing was done individually in a sound-attenuated booth and listeners indicated their responses by pressing buttons on a solid-state keyboard. A video display was also located in the booth.

Procedure. Participants were told that they would be hearing patterns of several sounds presented very quickly. They were told that some of the patterns were designated as targets and that their task would be to pick out the targets. Although the participants were told that the targets and nontargets would occur equally often, no information was provided regarding the composition of the target set. The six point rating scale was also explained (1 = definitely a nontarget, 2 = probably a nontarget, 3 = possibly a nontarget, 4 = possibly a target, 5 = probably a target, 6 = definitely a target). Participants in the semantic conditions were also read the following paragraph before beginning: "All of the individual sounds relate to water and steam. You will hear such things as drips, water flushing down a drain, a valve being turned on, steam escaping, and radiator pipes clanging."

Each trial began when the word "LISTEN" appeared on the video screen. A response prompt, the six scale descriptors, was presented immediately after the test pattern. The listener then responded by pressing a key on the keypad (a digit between "1" and "6"), and verbal feedback was presented visually following the response. After an intertrial interval of 1.5 s, the screen was erased and the next trial began. There were 96 trials in each test block, four presentations of each of the 12 targets and 48 presentations of nontargets. Listeners were tested for 12 blocks over three successive days.

Immediately after the last test block, listeners were told that the target patterns had been constructed using a set of rules--like the rules of language. It was explained that they would be hearing a new set of patterns and that their task would be to classify each pattern using the six-point rating scale. They then completed an additional block of 96 trials as before, but without feedback. The grammatical patterns presented in this test block were produced by the same finite-state grammar used for the grammatical target patterns; however, they were not presented as targets previously. This block was included to determine whether the participants could classify novel grammatical patterns. The participants were interviewed and debriefed before leaving.

Results & Discussion

A ROC function was determined from the rating-scale data for each participant on each test block (Swets, 1979). A nonparametric, response-bias-free index of performance was then computed by determining the area under the ROC using a trapezoidal algorithm. Mean areas were calculated for each condition by averaging across individuals. The mean ROC area for each of the four groups is plotted by blocks in Figure 1.

Insert Figure 1 here

Consider first the effect of syntactic pattern structure on classification performance. It is evident from Figure 1 that participants in the two grammatical groups (mean ROC area = .81) performed at a considerably higher level than did those in the two nongrammatical groups (mean ROC area = .60). This finding is consistent with our earlier result and indicates that individuals are able to use the underlying temporal structure of target patterns to facilitate classification.

The effect of semantic information is more subtle. In our previous experiment semantic information led to a slight, but consistent overall improvement in classification performance for individuals receiving structured target patterns. It is apparent from Figure 1 that in the present experiment, overall performance is very similar for the two grammatical groups (mean ROC areas of .82 and .80 for the semantic and no-semantic conditions, respectively). Nevertheless, it is interesting to note that on each of the first six test blocks, individuals who were provided with explicit semantic information outperformed those who received no explicit information. This trend is consistent with our previous finding. It suggests that in the present experiment any effect of explicit semantic information had disappeared by the seventh test block.

Two explanations exist for this result. First, it is possible

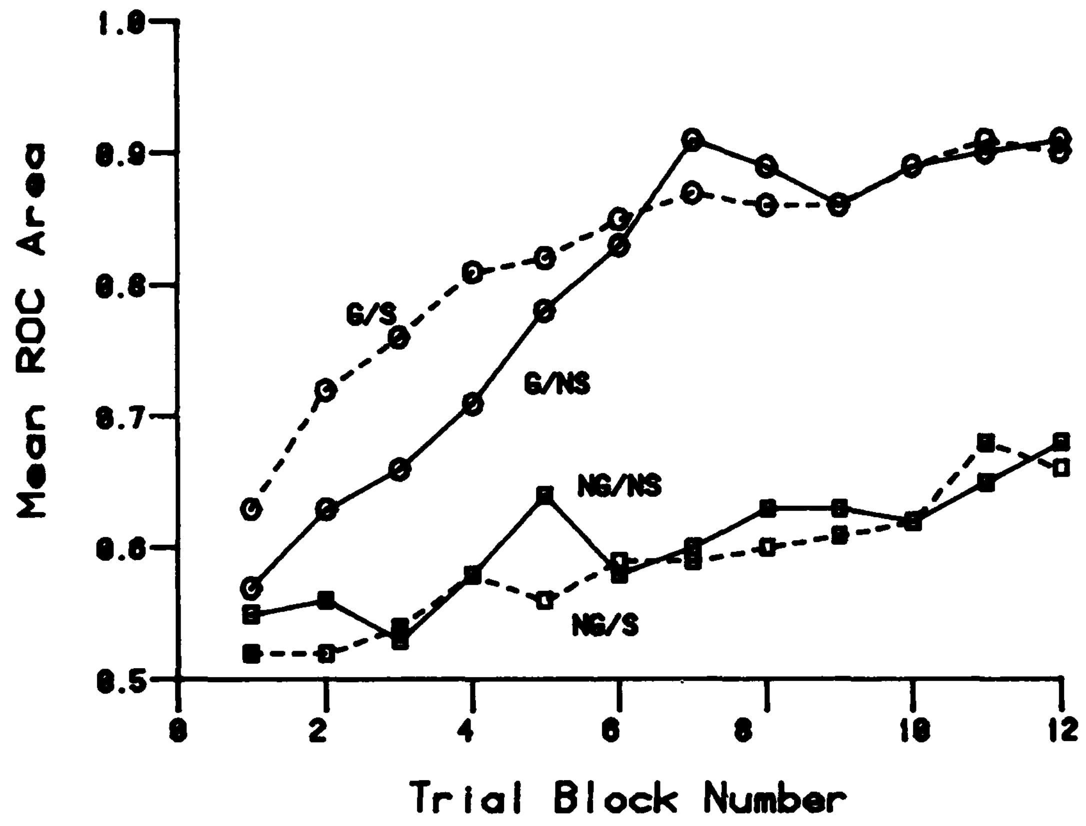

Figure 1. Mean ROC area by block for the grammatical (G) and nongrammatical groups (NG), with (S) and without (NS) explicit semantic information.

that with experience individuals in the no-semantic condition were able to develop their own labels and descriptive scenarios for the target patterns. This hypothesis seems likely given the small number of different sounds employed here (five) and the relative familiarity of these sounds. Individuals in the semantic condition were provided with an appropriate semantic framework for the patterns initially and consequently began performance at a higher level. Second, it is also possible that the convergence of the two groups reflects simple artifact--a ceiling effect. Although theoretically, the ROC area can reach a value of 1.00 with perfect performance, most individuals showed surprisingly stable asymptotic performance across the final six test blocks.

Another outcome of our previous experiment was that individuals who classified unstructured target patterns did not benefit from the explicit semantic information we provided. A similar finding is evident for the nongrammatical groups in the present study. Mean overall performance was very similar for the two groups (mean areas of .59 and .61 for the semantic and no-semantic conditions, respectively). Furthermore, inspection of Figure 1 reveals no systematic differences between the two nongrammatical groups.

Mean ROC areas were also computed for the final test block on which participants classified novel grammatical patterns without feedback. The purpose of these trials was to determine if individuals could generalize their knowledge of the target-pattern structure to previously untested grammatical patterns. Both grammatical groups performed substantially above the .50 chance level (mean ROC area of

.73 and .87 for the semantic and no-semantic conditions, respectively), whereas the two nongrammatical groups responded at chance level (mean ROC areas of .51 and .53 for the semantic and no-semantic conditions, respectively). These findings are consistent with our previous work and support the argument that participants in the grammatical groups learn something about the underlying structure of the target set during classification. That is, they learn something more general than simple paired-associate responses to individual patterns. Since individuals in the nongrammatical groups were not exposed to structured target stimuli, it is obvious that they would not be expected to perform any better than chance on this block.

Experiment 2

In general, the findings of Experiment 1 are consistent with our earlier results (Howard & Ballas, 1980) in revealing that syntactic and semantic factors interact in an important way to influence classification performance for complex nonspeech patterns. The grammatical and nongrammatical conditions investigated in Experiment 1, however, represent two extreme conditions. On the one hand, the target patterns are both interpretable and have an underlying temporal structure (grammatical conditions), whereas on the other hand the target patterns were not interpretable nor did they have any underlying syntactic or temporal structure. Consequently, the syntactic effects demonstrated in the previous experiment can be attributed either to pattern interpretability or to the presence of an underlying temporal structure. In the present experiment, two additional conditions were tested to address this issue. Specifically, grammatical target patterns were employed in a target classification task, however, the patterns were constructed so as to be generally uninterpretable. This was accomplished by permuting the assignment of pattern component sounds to the output of the finite-state grammar used in Experiment 1. In other words, the target patterns were grammatically structured, but unlike those used in the first experiment, they were not consistently interpretable. As before, one-half the participants received general semantic information regarding the sounds.

Method

Participants. Ten student volunteers, five in each of two groups, were paid to participate in the experiment. No individual had participated in the previous experiment.

Stimuli. The same five "real-world" sounds and finite-state grammar used in Experiment 1 were used to produce the stimulus patterns. The assignment of component sounds to the output codes produced by the grammar was determined randomly to minimize interpretability of the target patterns. The nontarget patterns were generated as in Experiment 1.

Apparatus. Same as Experiment 1.

Procedure. Same as Experiment 1.

Results & Discussion

A ROC area was determined for each individual on each block as in Experiment 1. The mean ROC area is plotted as a function of block for the two semantic conditions in Figure 2.

Insert Figure 2 here

Two results are evident in Figure 2. First, individuals in both semantic information conditions showed a consistent improvement in performance with practice. Indeed, their performance more closely approximates that of the grammatical group in Figure 1 than that of the nongrammatical group. The mean overall performance level observed in this experiment (mean ROC area of .80) is virtually identical to the mean performance level obtained for the grammatical group in Experiment 1 (mean ROC area of .81). Since the target patterns employed in the present experiment were structured, but interpretable, this suggests that performance depends more on syntactic pattern structure than on pattern interpretability per se.

Second, despite the similarities already noted, important differences also exist between the present results and those of Experiment 1. In particular, individuals in the no-semantic condition outperformed those in the semantic condition on all but a single block in the present experiment (block 5). This pattern differs from that observed in our previous research (Howard & Ballas, 1980) and in Experiment 1 for individuals classifying grammatically structured targets. It appears that the general semantic information we provided actually interfered with classification performance for structured, but uninterpretable patterns. This result suggests that when working with target patterns that are generally uninterpretable, specific thematic information may inappropriately lead individuals to search

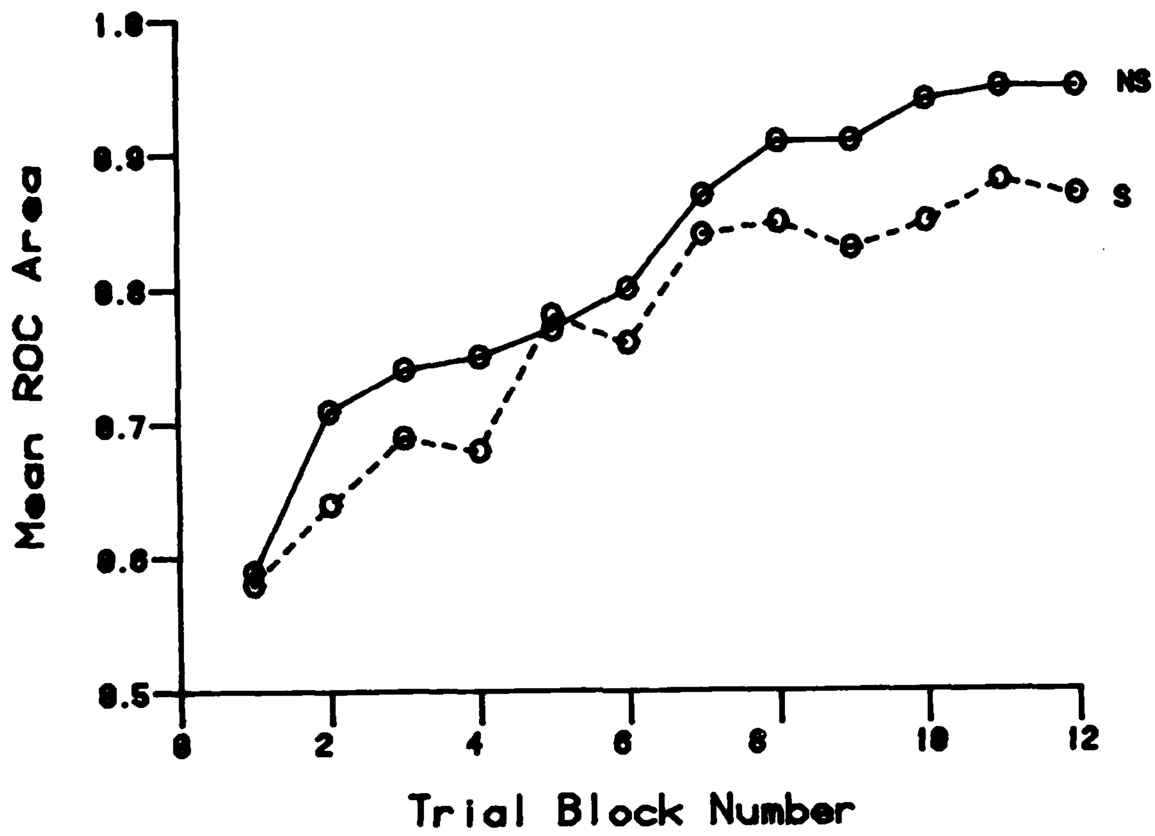

Figure 2. Mean ROC area by block for the two structured, uninterpretable groups of Experiment 2, with (S) and without (NS) explicit semantic information.

for sensible interpretations of the patterns where none exist. This misguided search may actually make the task more difficult. A similar tendency for semantic information to impair performance with uninterpretable, nongrammatical patterns was noted in our previous research (Howard & Ballas, 1980).

Mean ROC areas were also computed for the last, no-feedback test block with novel grammatical patterns. Individuals in both semantic conditions performed considerably above chance as expected (mean ROC areas of .77 and .81 for the semantic and no-semantic conditions, respectively).

General Discussion

The results of the present experiments are consistent with our earlier findings in revealing that both syntactic (sequential structure) and semantic factors can play a role in nonspeech pattern classification. In particular, Experiment 1 demonstrated that when listeners are required to classify sequentially structured, interpretable target patterns they are able to use this information to facilitate the task. Furthermore, the results of Experiment 2 showed similarly high performance for listeners who classified structured, but minimally interpretable patterns. This suggests that pattern structure rather than interpretability *per se* is largely responsible for the enhanced performance observed in Experiment 1. The finding that listeners in the structured or grammatical groups successfully generalized their knowledge to classify novel grammatical patterns on a post-experimental test block is consistent with the argument that listeners are able to learn general characteristics of the pattern structure.

The present experiments also showed that explicit semantic information can lead to enhanced classification performance--at least on initial trials--when the target patterns are consistently interpretable. On the other hand, when the target set is not interpretable, explicit semantic information leads to no improvement (Experiment 1) or to a performance decrement (Experiment 2). As suggested in our earlier paper (Howard & Ballas, 1980), it is likely that providing explicit semantic information leads listeners to search for a consistent semantic interpretation for the target pattern set. When no consistent interpretation exists, the classification task can actually become more difficult.

In general, it is clear that further work is needed to clarify the role of both syntactic and semantic factors in the perception of complex nonspeech patterns. Such factors are likely to play an important role in understanding the comprehension of everyday sounds as well as specialized tasks such as that of the sonar technician.

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Footnotes

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